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Physiochemical and rheological characterizations of Jordanian durum wheat cultivars and landrace*

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Abstract

The demand for wheat in Jordan has risen in recent years due to the growing need for various cereal products. This study aimed to investigate different wheat cultivars grown in Jordan. The physicochemical and rheological properties of twelve Jordanian landrace and durum wheat cultivars were examined, including Acsad 1186, Hourani, Acsad 1105, Norsi, Maru 1, Acsad 1103, Sham 1, Acsad 1131, Acsad 1115, Acsad 1315, and Deiralla 6. These cultivars were cultivated at the National Agricultural Research Center in Maru, Jordan. The experiment followed a randomized complete block design with three replications. A correlation analysis was performed to assess relationships among the measured parameters. The findings showed that the protein content ranged from 8.4% to 15.5%, and the moisture percentages ranged from 8.47% to 10.73%. The yield indicators for hectoliter and 1000-grain weight were reported as 82.66 kg/ha and 55.93 g for Maru 1 and Acsad 1105, respectively. All tested cultivars demonstrated a high falling number, indicating low alpha-amylase activity. The rheological properties of the samples were evaluated using Alveograph and Mixolab. Hourani had the highest water absorption (69.30%), dough extensibility, and swelling index, while Acsad 1315 showed the greatest dough tenacity and deformation energy. Dough stability varied across samples, ranging from 2.64 mins to 8.99 mins. Furthermore, correlation coefficients revealed strong links between water absorption and Mixolab starch-related parameters (C3, C4, C5), while no correlation was found between protein content and Alveograph metrics. Based on these results, Jordanian wheat cultivars exhibited significant variations in composition and rheology, offering valuable insights for breeding strategies aimed at improving functional properties.

Keywords

wheat cultivars; alveograph; falling number; grains; hectoliter; mixolab; thousand kernel weight; Rheology

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Introduction

Globally, wheat (*Triticum durum* Desf.) ranks among the most cultivated crops and is regarded as one of the most important cereal grains, providing energy and protein to the population. Additionally, its viscoelastic characteristics allow wheat dough to be processed into numerous derivative products, including bread, pasta, biscuits, noodles, and more (Yao et al. 2025). As a result, it serves as a raw material for several commonly consumed foods, making wheat a staple in numerous countries (Ferreira et al. 2025).

According to the USDA Foreign Agricultural Service (2024), global production in 2024 was expected to be 787 million tons. Locally, Jordanians consume approximately 30,000 tons of wheat per week, which is equivalent to the country's annual production. However, the yearly consumption reaches about 975,000 metric tons. Jordan is regarded as a dry area that faces several challenges in cultivating crops. The challenges had led to a decline in Jordan's wheat production. For that, the country relies on wheat imports from abroad. Jordan continues to aim to boost local wheat cultivation and enhance supply by implementing policies that support and promote farming and crop improvement initiatives, thereby ensuring food security. Researchers in Jordan are working to develop wheat cultivars that can withstand the country's climatic conditions, particularly drought, and increase yields to meet the rising demand for wheat (Jaradat 2013; Bani Khalaf et al. 2023).

The wheat grown in Jordan encompasses various cultivars, notably durum wheat, which is recognized for its high protein content and is primarily used in the production of pasta and baked goods (Othmani et al. 2022). Farmers and breeders have recently begun developing locally traditional wheat cultivars through natural or farmer selections (Jaradat 2013), and these enhanced cultivars have been named to reflect the culture, area, and other purposes. These enhanced wheat cultivars are referred to as landraces (Othmani et al. 2022). Therefore, understanding the physicochemical and rheological properties of landrace wheat cultivars is essential for breeders and millers to select the appropriate wheat cultivar for specific applications (Hrušková and Šmejda 2003).

The quality of wheat flour is determined through physicochemical and rheological analyses (Alhendi et al. 2022). Key indicators include chemical composition, 1,000 kernel weight, and hectoliter measurements, which assess composition and milling properties. Alveograph and Mixolab tools provide valuable insights into dough behavior under simulated handling conditions, offering data on extensibility, elasticity, protein stability, and starch behavior. These findings help predict industrial performance and guide cultivar selection (Zhygunov et al. 2022). Given the limited research on Jordanian landrace and durum wheat cultivars, this study examines the physicochemical and rheological properties of twelve local cultivars.

Materials and methods

Sample collection

Twelve landrace and durum wheat varieties were investigated to study their physico-chemical and rheological properties. The wheat cultivars included Hourani, Acsad 1105, Norsi black, Norsi white, Maru 1, Acsad 1103, Sham 1, Acsad 1131, Acsad 1115, Acsad 1315, and Deiralla 6. 10 kilograms were collected from each cultivar. All wheat cultivars were cultivated at the National Agricultural Research Center in Jordan. The production year was 2022. All samples underwent cleaning and separation from broken grains and foreign substances.

Sample preparation

All samples were cleaned and conditioned to the appropriate moisture content by adding 5 to 6% moisture. After that, the conditioned wheat samples were milled and sieved to achieve a particle size of 180 µm. Finally, all sieved samples were labeled and refrigerated until they were analyzed. All sample preparation and analysis procedures were done at a commercial mill (South Amman Mill, Jordan).

Physicochemical characteristics

Chemical analysis

The chemical composition—moisture, protein, fat, ash, and fiber—was measured following the AACC procedures (2000), while the carbohydrate content was calculated by difference.

Thousand kernel weight

One hundred grams of each weight cultivar were taken, and the sound and unbroken kernels were counted. The results are represented as grams per 1,000 kernels.

Hectoliter weight

AACC method no. 55-10.01 was used to measure the hectoliter weight for each wheat cultivar. The results were represented as kg/hl (AACC 2010).

Falling number

The falling number is widely used as an indicator of alpha-amylase activity. Lower values of falling numbers reflect high enzymatic activity. The falling number of wheat cultivars was measured according to AACC (2000) Method No. 56-81B using the Falling Number Apparatus (Perten, Sweden) Type 1900.

Rheological properties

Alveograph test

The rheological properties of wheat cultivars were assessed using the Alveograph device (Chopin, France), following the ICC Method 121, AACC Method 54- 30A, and ISO 5530-4 (ICC 1994; AACC 2000; ISO 2004). The analysis was conducted under controlled humidity conditions of 14%. The flour sample's water absorption was determined using the Consistograph, following the AACC (2000) Method No. 54–50. The obtained values were then incorporated into the Alveograph test. Five parameters were determined, including dough tenacity, which is the maximum pressure required to inflate the dough bubble (p-value). Dough extensibility refers to the ability of the dough to be extended before it breaks down (L-value). The swelling index (G) is another measure of extensibility. Baking strength (W), or deformation energy, represents the amount of energy required to inflate the dough to the point of deformation. The configuration ratio (P/L) of the Alveograph curve and the elasticity index (Ie), measured as a percentage, and were also assessed to further characterize dough behavior.

Mixolab analysis

Mixolab (MIXOLAB 2, CHOPIN, France), using the ICC Method 173 ICC (2008), was used to determine the thermomechanical properties of wheat dough during the mixing, heating, and cooling stages. Six parameters were determined that reflect the dough protein development and stability: C1 (torque, peak torque of dough development), C2 (during heating, protein weakening is measured), and torques C3, C4, and C5, which indicate the starch properties: C3 (starch gelatinization during heating), C4 (starch pasting or gel formation), and C5 (starch retrogradation during cooling). At the beginning of heating and initial mixing, the temperature is held at 30 °C, and the wheat flour components start to absorb water. This forms a protein (gluten) network, leading to the development of a viscoelastic structure. The torque reaches its maximum during the initial phase as the formed protein network resists the mechanical mixing force. Then, due to continuous mixing, the C2 torque value drops as protein weakens, resulting in lower resistance. In the third phase, as the temperature increases, wheat starch granules absorb water and swell, resulting in an increase in viscosity known as starch gelatinization. The fourth stage, C4, indicates amylolytic activity and starch gel stability, which indicate product stability during storage. In the final stage, the torque reduces due to starch reassociation and retrogradation.

Statistical analysis

Statistical analysis was conducted using the SAS statistical program (version 9), with data expressed as the mean of three replicates accompanied by their standard deviations. The experiment followed a randomized complete block design with three replications, and differences between means were evaluated using Duncan's Multiple Range Test at a significance level of $p \leq 0.05$.

Results and discussion

Physicochemical properties

Chemical analysis

This research compares the physicochemical and rheological properties of durum and landrace wheat cultivars. Table 1 shows that moisture content, protein, and carbohydrates varied significantly among the wheat cultivars. As all wheat cultivars experienced the same growing conditions and environmental factors, including irrigation, fertilizer use, soil, and rainfall volume, the differences in chemical composition may be linked to variations in genetic factors across wheat cultivars.

Protein content is one of the most critical factors affecting milling and quality properties. The protein content varies significantly among wheat cultivars. As shown in Table 1, Norsi black shows the highest protein content (15.5%), while Acsad 1115 has the lowest (8.4%). As mentioned, this variation in protein content can be linked to variations in genetic factors. A similar range was reported by Channa et al. (2015), who found variations in the protein content of twelve Pakistani durum wheat cultivars, ranging from 9.68% to 13.45%. Also, our results are consistent with those obtained by Sayaslan et al. (2012), who found that the protein content of twelve Turkish durum wheat cultivars ranged from 10.7% to 16.8%. Additionally, El-Khayat et al. (2006) reported that the protein content of Syrian wheat ranged from 10.7% to 14.1%, attributing these results to the nitrogen content in the soil.

Table1 indicates that the moisture content of wheat cultivars varies between 8.47% and 10.73%. Moisture content has a direct impact on milling properties, product quality, and storage stability. Wheat cultivars Maru 1 and Acsad 1103 have the lowest moisture content among the twelve cultivars. However, Acsad 1115 has the highest moisture content of 10.73%. These low moisture values reflect Jordan's dry environment in which the durum wheat cultivars are grown. These results align with those reported by El-Khayat et al. (2006), who reported that the moisture content of several Syrian durum wheat samples ranged from 8.1% to 9.1%. However, other studies reported the moisture levels, ranging from 10.25%–11.41% (Othmani et al. 2022) and 10.0–12.0% (Jabeen Channa et al. 2015).

The ash content, which indicates the mineral content, ranges from 1.02% to 1.31% for Acsad and Hourani, respectively, with slight variation among wheat cultivars. In comparison, Syrian genotypes have an ash content ranging from 1.45% to 1.74% (El-Khayat et al. 2006). Additionally, the ash content for eight Indian wheat varieties ranges from 1.16% to 1.60% (Baljeet et al. 2017).

The Norsi black had the lowest carbohydrate content, while Acsad had the highest, 77.54%. This variation may be attributed to genetic factors. Carbohydrate content plays a role in determining the use of wheat in certain food products.

Thousand kernel weight

Table 1 indicates a significant variation among all wheat cultivars. One thousand grains were analyzed for all wheat cultivars, which is crucial for understanding wheat milling properties (Banu and Aprodu 2015). The 1000-grain weight is used to indicate yield. Thus, as the 1000-grain weight is high, it represents a higher flour yield. (Ebrahimnejad and Rameeh 2016; Othmani et al. 2022). In addition, Zhygunov et al. (2022) linked the differences to the growth conditions and the wheat variety. The lowest 1000-grain weight value was determined for Acsad 1186 (33.71 g) and the highest for Acsad 1105 (55.93 g). These results fall within the acceptable range of 1000 grain yield, 30–35 g (Petrova 2007). Additionally, these results align with those reported by El-Khayat et al. (2006), who noted a high milling yield in nine spring durum wheat genotypes grown in Syria, with a 1000-grain weight of 42.5–55.5 g. It was also reported by Othmani et al. (2022) that the 1000 kernel weight of eight Tunisian durum wheat genotypes was high, ranging from 39.35 g to 59.7 g. Canay et al. (2022) reported similar ranges for a 1000-grain weight ranging from 37.08 g to 51.92 g for eight wheat cultivars grown in Anatolia.

Hectoliter weight

Hectoliter weight, a key test metric, serves as an indicator of flour yield. Table 1 reveals that Maru 1 achieved the highest hectoliter value of 82.66 kg/hL, reflecting its denser grains and, consequently, superior flour yield. Conversely, Acsad 1131 recorded the lowest hectoliter weight at approximately 66.81 kg/hL, indicating a reduced flour yield. Generally, a test weight exceeding 76 kg/L is considered suitable for industrial applications. Thus, the majority of wheat cultivars examined in this study meet the necessary standards. According to the study by Baljeet et al. (2017), who found the test weight of eight Indian wheat varieties in the range of (79.25–83.99 kg/hl). In another study conducted by Banu and Aprodu (2015), which focused on twenty-five European wheat varieties, the hectoliter ranged from 74.4 to 82.8 kg/hL. Moreover, El-Khayat et al. (2006) observed that the high-test weight for Syrian wheat genotypes, ranging from 83.1 to 85.9 kg/hL. Additionally, a study by Canay et al. (2022) reported that the test weight of wheat cultivars in Anatolia ranged from 75.05 kg/hL to 79.9 kg/hL.

Falling number

Table 1 shows that the Jordanian wheat cultivars vary widely in falling numbers, ranging from 321.67 seconds for Acsad 1131 to 760 seconds for Norsi white. The wide variation may be attributed to genetic differences and storage conditions. The high falling numbers indicate low sprouting, resulting in low alpha-amylase activity and lower starch damage. According to a study by Petrova (2007), wheat with a falling number of 250 to 500 seconds is acceptable. The high variation in the falling numbers of Jordanian wheat cultivars highlights the importance of selecting the appropriate type of wheat according to its intended use, as enzyme activity can significantly affect the final product quality and dough behavior.

Rheological properties

Alveograph

Water absorption indicates the amount of water that a specific quantity of flour can absorb, providing insights into yield and predicting shelf life (Jabeen Channa et al. 2015). Wheat cultivars exhibited some variation in water absorption. Table 2 shows that the highest value was recorded for Hourani at 69.30%. According to Munteanu et al. (2016), water absorption percentage higher than 65% is considered very satisfactory for breadmaking. Additionally, high water absorption levels are preferred in bread processing, as they are crucial for flexibility during fermentation and baking. Conversely, Acsad 1131 displayed the lowest value of 55.16%, which is also classified as a satisfactory percentage. These results were comparable to those reported

Table 1. Chemical and physical properties of Jordanian Durum wheat variates.

Wheat Cultivar	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	Fiber (%)	Carbohydrate (%)	Falling number (sec)	Hectoliter kg /100 liters	1000 grain weight (g)
Acsad 1186	9.07 ^{e}	13.20 ^{c}	2.41 ^{b}	1.16 ^{bcd}	1.19 ^{ab}	72.97 ^{fg}	542.67 ^{f}	78.28 ^{e}	33.71 ^{h}
Hourani	9.47 ^{d}	11.00 ^{g}	3.15 ^{a}	1.31 ^{a}	1.13 ^{ab}	73.93 ^{de}	486.33 ^{h}	79.29 ^{d}	38.91 ^{g}
Acsad 1105	8.77 ^{f}	10. 50 ^{h}	1.96 ^{cdef}	1.16 ^{bcd}	1.07 ^{b}	76.47 ^{b}	585.33 ^{e}	79.85 ^{c}	55.93 ^{a}
Norsi black	8.83 ^{ef}	15.50 ^{a}	1.83 ^{def}	1.12 ^{cde}	1.24 ^{a}	71.58 ^{h}	686.33 ^{b}	76.01 ^{f}	51.72 ^{bc}
Norsi white	8.97 ^{ef}	14.40 ^{b}	1.78 ^{ef}	1.10 ^{cde}	1.15 ^{ab}	72.54 ^{g}	760.33 ^{a}	79.54 ^{cd}	52.25 ^{b}
Acsad 1275	8.47 ^{g}	14.00 ^{b}	2.27 ^{bcd}	1.17 ^{bcd}	1.26 ^{a}	72.63 ^{g}	610.00 ^{d}	82.66 ^{a}	50.03 ^{d}
Acsad 1103	8.47 ^{g}	12.00 ^{e}	2.38 ^{bc}	1.11 ^{cde}	1.15 ^{ab}	74.96 ^{c}	650.00 ^{c}	80.40 ^{b}	44.69 ^{e}
Sham 1	9.83 ^{c}	12.40 ^{de}	1.98 ^{cdef}	1.26 ^{ab}	1.22 ^{a}	73.45 ^{ef}	398.33 ^{i}	72.60 ^{g}	41.16 ^{f}
Acsad 1131	10.43 ^{b}	12.70 ^{d}	1.55 ^{f}	1.02 ^{e}	1.21 ^{a}	73.15 ^{fg}	321.67 ^{j}	66.81 ^{k}	34.55 ^{h}
Acsad 1115	10.73 ^{a}	8.40 ^{l}	1.67 ^{ef}	1.07 ^{de}	1.15 ^{ab}	77.54 ^{a}	390. 00 ^{i}	69.90 ^{j}	52.68 ^{b}
Acsad 1315	9.60 ^{cd}	12.00 ^{e}	1.61 ^{if}	1.08 ^{de}	1.23 ^{a}	74.56 ^{cd}	490.33 ^{h}	72.03 ^{h}	40.76 ^{fg}
Deiralla 6	9.40 ^{d}	11.500 ^{f}	2.05 ^{bcde}	1.23 ^{abc}	1.18 ^{ab}	74.36 ^{cd}	518.33 ^{g}	71.12 ^{i}	48.72 ^{d}

Different letters in the same column indicate significant differences among samples ($p < 0.05$).

by Jabeen Channa et al. (2015), who state that the water absorption of seventeen wheat varieties grown in Sindh ranged from 68.5% to 79%. However, lower water absorption was observed in 53.7% to 56.8% of Indian wheat varieties (Baljeet et al. 2017).

The alveograph results showed a significant variation between alveograph parameters across Jordanian durum and landrace cultivars. For P (dough tenacity) and W (deformation energy) parameters, Acsad 1315 has the highest values of all cultivars (P = 120.0 mm, W = 133.0 × 10^{-4} J), indicating a firmer dough that resists deformation, requiring higher deformation energy. In contrast, Acsad1105 has the lowest values (P = 55.0 mm, W = 53.3 × 10^{-4} J), suggesting weak dough properties, preferably good baking properties for cookies and biscuits, as the dough will expand during baking. Thus, it should be low resistant to deformation, giving the flexibility for dough expansion (Zhygunov et al. 2022). However, Vazquez and Veira (2015) stated that the Alveograph W value was 180–462 × 10^{-4} J for a range of Uruguayan genotypes, which is higher than our obtained results. L (Dough Extensibility) is a parameter that measures the dough's ability to extend before rupture. The G index (swelling index) is another parameter that measures dough extensibility (stretchability). Subsequently, the factors affecting the L-value are the same as those involving the G index (Jødal and Larsen 2021). The Hourani cultivar had the highest extensibility values (L = 52.67 mm, G = 15.30 mm), Table 2, suggesting a dough that can be extended more during fermentation and baking processing. Zhygunov et al. (2022) reported L values < 40 mm for four species of wheat.

In addition, Table 2 shows a wide variation in the cultivars between dough strength and stretchability (p/L). Deiralla6 reported the highest p/L ratio of 5.73, indicating that the firm dough may be challenging to stretch. The lowest P/L ratio was reported for Hourani and Maru 1 at 1.54, indicating weak and extensible dough properties. According to Zhygunov et al. (2022), a higher resistance to extension suggests suitability for bread making, while a lower ratio indicates optimal characteristics for biscuit production.

Mixolab

One of the advantages of the Mixolab device is its ability to measure protein and starch properties, as well as amylolytic enzyme activity, all in a single set. C1 torque (dough consistency) and C2 torque (protein weakening) are parameters associated with protein quality, particularly gluten content. In contrast, C3 torque (starch gelatinization), C4 torque (amylolytic activity), and C5 torque (starch retrogradation) pertain to starch properties. Koksel et al. (2009). Table 3 shows the results of the mixolab parameters of Jordanian wheat durum and landrace cultivars.

Table 3 shows that Acsad 1315 exhibited the highest stability (8.99 minutes), indicating superior resistance to deformation (firm dough) during mixing. In contrast, the Norsi white and Norsi black displayed the lowest stability (2.57 and 2.64 minutes), suggesting that their dough weakens quickly during processing. The stability parameter is crucial for determining the best flour from wheat cultivars for specific applications. For example, firm dough with high stability values is ideal for making pizza and bread, enabling the baker to handle the dough more easily (Baljeet et al. 2017). Wheat with low stability values is suitable for softer products, such as cakes and crackers, like the Norsi black cultivar (stability 2.64 min). A similar stability range was reported for Indian wheat varieties, between 1.43 and 9.13 minutes (Baljeet et al. 2017), and 3.42 to 6.67 minutes for Nigerian wheat varieties (Gloria et al. 2017). Moreover, dough consistency varied significantly (P < 0.05) from 0.97 Nm for Acsad 1103 to 4.18 Nm for Acsad 1315. Higher C1 torque values indicate a firmer dough, as shown in Acsad 1315, making this cultivar suitable for bread making. In contrast, lower values suggest less resistance in the dough, making it ideal for soft dough.

Additionally, C2 torque, an indicator of protein weakening, exhibits significant variation among wheat cultivars due to their inherent differences. The lowest values were recorded for Norsi black at 0.24 Nm and Acsad 1186 at 0.32 Nm, indicating considerable weakening of the protein. Generally, C2 torque exhibits the lowest torque value compared to other torques due to thermal processing. Values below 0.4 Nm indicate that the flour dough has a low mixing

Table 2. Parameters measured by the alveograph of Jordanian Durum wheat varieties.

Wheat Cultivar	Water absorption (%)	P-value (mm)	L-value (mm)	G	W (10^{-4} J)	P/L ratio	Ie
Acsad 1186	62.46 ^{bc}	96.00 ^{c}	30.67 ^{d}	12.50 ^{c}	113.67 ^{b}	3.13 ^{cd}	37.00 ^{d}
Hourani	69.30 ^{a}	81.00 ^{e}	52.67 ^{a}	15.30 ^{a}	89.67 ^{d}	1.54 ^{g}	27.00 ^{gh}
Acsad 1105	63.00 ^{bc}	55.00 ^{h}	24.66 ^{gh}	11.30 ^{e}	53.33 ^{g}	2.23 ^{f}	32.00 ^{ef}
Norsi black	63.23 ^{bc}	72.00 ^{f}	29.00 ^{de}	11.70 ^{de}	71.67 ^{f}	2.48 ^{e}	34.00 ^{de}
Norsi white	61.63 ^{cd}	82.00 ^{e}	26.33 ^{efg}	11.80 ^{d}	82.00 ^{e}	3.12 ^{cd}	29.67 ^{fg}
Maru 1	60.16 ^{de}	71.00 ^{fg}	46.00 ^{b}	15.20 ^{a}	104.67 ^{c}	1.54 ^{g}	26.23 ^{fg}
Acsad 1103	59.26 ^{e}	87.33 ^{d}	26.00 ^{fgh}	11.60 ^{de}	88.67 ^{d}	3.36 ^{c}	26.00 ^{h}
Sham 1	63.93 ^{b}	100.00 ^{c}	23.33 ^{hi}	10.37 ^{fg}	90.00 ^{d}	4.30 ^{b}	43.00 ^{c}
Acsad 1131	55.16 ^{f}	55.33 ^{h}	34.33 ^{c}	13.20 ^{b}	70.00 ^{f}	1.62 ^{g}	31.00 ^{ef}
Acsad 1115	60.00 ^{de}	67.00 ^{g}	21.67 ^{ij}	10.03 ^{fg}	53.67 ^{g}	3.11 ^{d}	41.00 ^{c}
Acsad 1315	60.40 ^{de}	120.00 ^{a}	28.33 ^{def}	11.90 ^{d}	133.00 ^{a}	4.24 ^{b}	48.33 ^{b}
Deiralla 6	63.16 ^{cd}	110.67 ^{b}	19.333 ^{j}	9.83 ^{g}	88.67 ^{d}	5.73 ^{a}	62.00 ^{a}

Different letters in the same column indicate significant differences among samples (p < 0.05).
P-value: dough tenacity; L-value: dough extensibility; G: dough swelling index; W: deformation energy; P/L: elasticity ratio; Ie: elasticity index.

Table 3. Parameters Evaluated by the Mixolab for Jordanian Durum Wheat Varieties.

Cultivar	Stability (Min)	C 1 (Nm)	C 2 (Nm)	C 3 (Nm)	C 4 (Nm)	C 5 (Nm)
Acsad 1186	5.70 ^{c}	1.1 ^{b}	0.32 ^{f}	1.6 ^{e}	1.45 ^{f}	2.02 ^{h}
Hourani	5.91 ^{bc}	1.19 ^{ab}	0.47 ^{a}	1.27 ^{g}	1.15 ^{h}	1.77 ^{i}
Acsad 1105	5.78 ^{c}	1.06 ^{b}	0.41 ^{c}	1.77 ^{bc}	1.72 ^{b}	2.86 ^{b}
Norsi black	2.64 ^{g}	1.09 ^{b}	0.24 ^{h}	1.38 ^{f}	1.3 ^{g}	2.26 ^{g}
Norsi white	2.57 ^{g}	1.14 ^{ab}	0.36 ^{e}	1.69 ^{cde}	1.64 ^{cd}	2.64 ^{c}
Maru 1	5.31 ^{d}	1.33 ^{a}	0.43 ^{b}	1.74 ^{cd}	1.65 ^{c}	2.55 ^{d}
Acsad 1103	6.02 ^{b}	1.09 ^{b}	0.39 ^{d}	1.78 ^{bc}	1.72 ^{b}	2.85 ^{b}
Sham 1	3.21 ^{f}	1.14 ^{ab}	0.38 ^{d}	1.4 ^{f}	1.08 ^{i}	1.77 ^{i}
Acsad 1131	6.11 ^{b}	1.15 ^{ab}	0.35 ^{e}	1.87 ^{ab}	1.82 ^{a}	2.97 ^{a}
Acsad 1115	3.10 ^{f}	1.07 ^{b}	0.28 ^{g}	1.91 ^{a}	1.59 ^{d}	2.46 ^{f}
Acsad 1315	8.99 ^{a}	1.11 ^{ab}	0.43 ^{b}	1.64 ^{de}	1.52 ^{e}	2.50 ^{e}
Deiralla 6	4.12 ^{e}	1.11 ^{ab}	0.39 ^{d}	1.65 ^{de}	1.47 ^{ef}	2.55 ^{d}

Different letters in the same column indicate significant differences among samples ($p < 0.05$).
C1: Dough development; C2: Protein weakening; C3: Starch gelatinization; C4: Dough pasting; C5: Starch retrogradation.

tolerance (Sharma et al. 2017). Our findings reveal that Acsad 1105, Acsad 1315, and Maru 1 have higher C2 values (0.47 Nm, 0.43 Nm, and 0.43 Nm, respectively), suggesting better mixing tolerance because of less protein weakening. The C2 results reported by Lacko-Bartoŝová et al. (2019) for spelt wheat cultivars ranged from 0.27 Nm to 0.39 Nm, influenced by both the cultivar and the growing year. The observed low C2 torque values indicate weak dough and restricted mixing tolerance(Lacko-Bartoŝová et al. 2019).

Furthermore, Mixolab also measures the starch properties. During the heating phase, the measured torque value C3 indicates starch gelatinization with a peak reported for Acsad 1131 at 1.87 Nm, highlighting the highest starch gelatinization and dough viscosity among the studied wheat cultivars. The stability of the starch paste, indicated by the torque value C4, was highest for Acsad 1131 at 1.82 Nm (Table 3). However, this value decreased when compared to C3 due to a change attributed to the activity of amylolytic enzymes. Consequently, the final product tends to have a soft texture due to the activity of these enzymes, which break down the starch paste and alter its consistency. In the cooling phase, a C5 torque of Acsad 1131 was 2.97 Nm, which indicates greater retrogradation.

Correlation among Traits

Pearson's correlation was used to explore the relationship among various parameters. The findings revealed a strong correlation among several parameters, while others showed no significant correlation. The detailed results of the correlation among all parameters are illustrated in Table 4.

Correlation between chemical properties

A highly significant relationship was detected between protein content and moisture levels ($R = -0.517$, $P < 0.01$), suggesting that increasing moisture content can dilute the protein, resulting in a negative correlation, these results are consistent with what they found by Buenavista-Jaralillo et al., (2025). Moreover, increasing the moisture content creates a suitable environment for enzymatic activity, affecting the falling number. Thus, a negative correlation was observed ($R = -0.833$, $P < 0.01$) between moisture and the falling number. Also, no correlation exists between moisture and the other chemical parameters. This was also observed by a study conducted by El-Khayat et al. (2006), who stated that the moisture content of Syrian wheat varieties did not correlate with other chemical properties.

A significant negative correlation ($R = -0.855$, $P < 0.01$) suggests that wheat cultivars with higher moisture levels tend to have lower grain density. This decreases the overall weight per unit volume, decreasing the hectoliter value.

Protein content showed a highly significant negative correlation ($R=-0.924$, $P < 0.01$) with carbohydrate content. Conversely, a positive correlation was observed between protein content and falling number ($R = 0.559$, $P < 0.01$), suggesting that increased protein content can create a stronger (gluten) network, leading to a higher falling number.

No correlation was found between hectoliter and protein content, although El-Khayat et al. (2006) reported a positive correlation. In addition, no correlation existed between ash and protein content, while El-Khayat et al. (2006) and Othmani et al. (2022), indicated a negative correlation.

Ash and fat positively correlate ($R = 0.458$, $P < 0.01$). This relationship may be attributed to the fat in the germ and the ash in the bran, which is indicative of whole-grain wheat.

Correlations between rheological properties

A strong positive correlation ($R = 0.951$, $P < 0.01$) exists between the G-value and L-value (dough extensibility), suggesting that dough from wheat cultivars with higher swelling starch results in dough with greater extensibility, this result were consistent with what obtain by Jødal and Larsen (2021). Conversely, more extensible doughs with a high G-value show a negative correlation with the P/L ratio ($R = -0.753$, $P < 0.01$), suggesting that swelling starch leads to a more resistant dough while enhancing extensibility. Furthermore, a high G-value correlates negatively with the elasticity index ($R=-0.644$, $P < 0.01$), as the swelling starch weakens the gluten network, reducing the dough's elasticity while maintaining its original state.

A high correlation was observed between dough tenacity (P-value) and deformation energy (W) ($R = 0.788$, $P < 0.01$). While the swelling index (G) and elasticity index (Ie) are negatively correlated, a high value of Ie indicates that the dough can effectively retain its original shape, resulting in low swelling. Consequently, the dough does not maintain its expansion, leading to a negative correlation (Zhygunov et al. 2020). Also, the swelling index (G) and the p/L ratio are negatively correlated ($r = -0.722$, $P < 0.01$). Higher p/L values indicate a greater ability of the tested dough to resist deformation, meaning it can withstand deformation. Therefore, when air is injected, its ability to stretch is affected. Firm dough does not expand well when air is injected, leading to a low G value (Jødal and Larsen 2021).

Table 4. Pearson's correlation coefficients among some chemical, physical and rheological properties parameters of the Jordanian durum wheat cultivars and landrace.

	Moisture	Protein	fat	ash	fiber	Carb	Falling number	Hectoliter	1000 grain	Water absorption	P-value	L-value	G	W energy	P/L Dough strength	Ie	Stability (Min)	Phase 1 C1	Phase 2 C2	Phase 3 C3	Phase 4 C4	Phase 5 C5
Moisture	1	-0.51 **	ns	ns	ns	ns	-0.833**	-0.855 **	ns	ns	ns	ns	ns	ns	ns	0.359*	ns	ns	ns	ns	ns	ns
Protein		1	ns	ns	0.333*	-0.924**	0.559**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	-0.330*	ns	ns
Fat			1	0.458**	ns	ns	ns	0.539**	ns	0.552**	ns	0.560**	0.50**	ns	ns	ns	ns	ns	0.446**	-0.458**	-0.365*	-0.458**
Ash				1	ns	ns	ns	ns	ns	0.612**	ns	ns	ns	ns	ns	ns	ns	ns	0.352*	-0.572**	-0.585**	-0.550**
Fiber					1	-0.393*	ns	ns	ns	ns	ns	ns	ns	0.353*	ns	ns	ns	ns	ns	ns	ns	ns
Carb						1	-0.345*	ns	ns	ns	ns	-0.345*	-0.406*	-0.375*	ns	ns	ns	ns	ns	0.482**	ns	ns
Full num							1.00	0.753**	0.510**	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Hectoliter								1	ns	0.371*	ns	0.405*	0.463**	ns	-0.363*	-0.593**	ns	ns	ns	ns	ns	ns
1000 grain									1.00	ns	ns	ns	-0.338*	-**	ns	ns	-0.483**	ns	ns	ns	ns	0.339*
Water absorption										1.00	ns	ns	ns	ns	ns	ns	ns	ns	ns	-0.744**	-0.762**	-0.723**
P-value											1.00	ns	ns	0.788**	0.788**	0.644**	ns	ns	ns	-0.346*	-0.428**	-0.375*
L-value												1.00	0.951**	ns	-0.722**	-0.571**	ns	0.473**	0.463**	-0.341*	ns	ns
G													1.00	ns	-0.753**	-0.644**	0.377*	0.502**	0.453**	ns	ns	ns
W														1.00	ns	ns	0.559**	ns	0.404*	ns	ns	ns
Energy																						
P/L															1.00	0.848**	ns	ns	ns	ns	ns	ns
Dough strength and extensibility																						
Ie																1.00	ns	ns	ns	ns	ns	ns
Stability (Min)																	1.00	ns	0.582**	ns	ns	ns
Phase 1																		1.00	0.350*	ns	ns	ns
C1																						
Phase 2																			1.00	ns	ns	ns
C2																						
Phase 3																				1.00	0.878**	0.798**
C3																						
Phase 4																					1.00	0.933**
C4																						
Phase 5																						1.00
C5																						

* and ** indicate significant correlation at the 0.05 and 0.01 level.
P-value: dough tenacity; L-value: dough extensibility; G: dough swelling index; W: deformation energy; P/L: elasticity ratio; Ie: elasticity index; C1: Dough development; C2: Protein weakening; C3: Starch gelatinization; C4: Dough pasting; C5: Starch retrogradation.

Correlation between mixolab and chemical parameters

C3, C4, and C5 are negatively correlated with fat content. Fat negatively correlates with starch gelatinization ($R = -0.458$, $P < 0.01$). This suggests that fat interferes with starch gelatinization during heating, leading to reduced starch gelatinization and lower C3 torque (Codină et al. 2019a). Additionally, fat may act as a barrier that prevents enzymes from accessing the starch granules and prevents starch reassociation, resulting in lower C4 and C5 torques (Codină et al. 2019a).

Correlation between alveograph and mixolab parameters

The results of the correlation analysis between water absorption and Mixolab parameters associated with starch properties (torque C3, C4, and C5) all revealed a similar trend. These parameters show a negative correlation with water absorption ($R = -0.744$, $R = -0.762$, and $R = -0.723$, respectively). These findings are consistent with the results reported by Singh et. al (2019), which indicated that C3, C4, and C5 parameters are negatively associated with water absorption in Indian flour wheat varieties. As water absorption increases, the amount of free water in the dough also rises, which dilutes the starch-protein matrix, thus reducing the effectiveness of swollen starch granules and decreasing their contribution to dough consistency; consequently, C3 torque reduces (Codină et al. 2019b). Furthermore, for C4 torque, the stability of starch paste is reduced because the diluted starch reduces the resistance to mixing. Additionally, the increased enzymatic activity that breaks down starch further reduces the resistance to mixing. C5 torque also shows a negative correlation; increased water absorption disperses the starch molecules, making their reassociation less effective, leading to lower observed retrogradation, which lowers the C5 torque (Codină et al. 2019b).

Conclusion

The physicochemical and rheological properties of twelve Jordanian landraces and durum wheat exhibited significant variability. All tested wheat cultivars displayed a high falling number, yet they demonstrated a broad range of protein content and dough stability, making them suitable for various processing applications. Furthermore, the correlation analysis revealed relationships between some rheological parameters. These findings can assist breeders in selecting wheat cultivars tailored to specific cereal production needs. Future research should focus on testing the final products to verify their processing quality.

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